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note reference to PULFER on dispersiveness of LPD

RADC-TR-69-191, Volume I
Final Technical Report
4 March 1969

ARPA ANTENNA STUDY
PART I - DISPERSION STUDY

Robert K. Greenough

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Phone: 315 477-7077

Project Engineer: C. S. Malagisi
Phone: 315 330-2443

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

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PART I - DISPERSION STUDY

Robert K. Greenough
Syracuse University Research Corp.

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FOREWORD

This report covers the tasks performed under Contract F 30602-67-C-0138, Exhibit Line Item A010. The report is in two parts, each covering a task related to the Big Push Radar Program. The tasks were approved and monitored by the Rome Air Development Center. The Project Engineer was Mr. Carmen Malagisi.

This technical report has been reviewed and is approved.

Carmen S. Malagisi

CARMEN S. MALAGISI
RADC Project Engineer
EMATA

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SECTION I

INTRODUCTION

The purpose of this contract was to perform studies for Rome Air Development Center and Advanced Research Projects Agency in the antenna development program for the Big Push Radar. The contribution by Syracuse University Research Corporation was in the form of man power and materials applied to specific antenna problems specified by Rome Air Development Center, and relating to the OHR program.

The first task under this contract was to consider the dispersive properties of the Log Periodic Dipole Array element when some of the dipoles were reactively loaded. This effort was primarily a literature search to determine what has been accomplished in loading of LPD elements, and in the study of dispersive properties of frequency independent antennas.

SECTION II

DISPERSION STUDY

The Log Periodic Dipole Array is a pseudo-frequency-independent antenna, capable of operating over a wide frequency band with essentially constant pattern and impedance characteristics. The application of the LPD in a wideband array requires the consideration of the farfield phase response with frequency as well as the amplitude response. Carrel[1] has shown that the phase is proportional to the logarithm of frequency, making it possible to adjust the phase of an LP antenna independent of the pattern and input impedance. This property has been and is being used in the design of arrays of LP antennas[2].

The LPD antenna is currently being considered as the element for the broadband array of the CONUS Antenna Modeling Study. The size of the antenna and the required proximity of the elements of the array dictate the need for foreshortening the dipoles at the low frequency end of some of these elements. This can be accomplished by reactively loading the longest dipoles of the LPD element to obtain a shortening factor of approximately two to one. The question has arisen as to the effect of this loading on the frequency response or dispersive properties of the LPD antenna with foreshortened elements, compared to the unloaded LPD. The purpose of this study was to determine the effects of loading on dispersion and to obtain some insight into the dispersion properties of the class of antennas which includes the LPD array.

1. FORESHORTENED DIPOLE ARRAY

A number of papers have been published describing methods for the foreshortening of elements of an LPD antenna[3, 4, 5, 6, 7]. Figure 1 shows some of the methods of loading of individual dipole elements to achieve

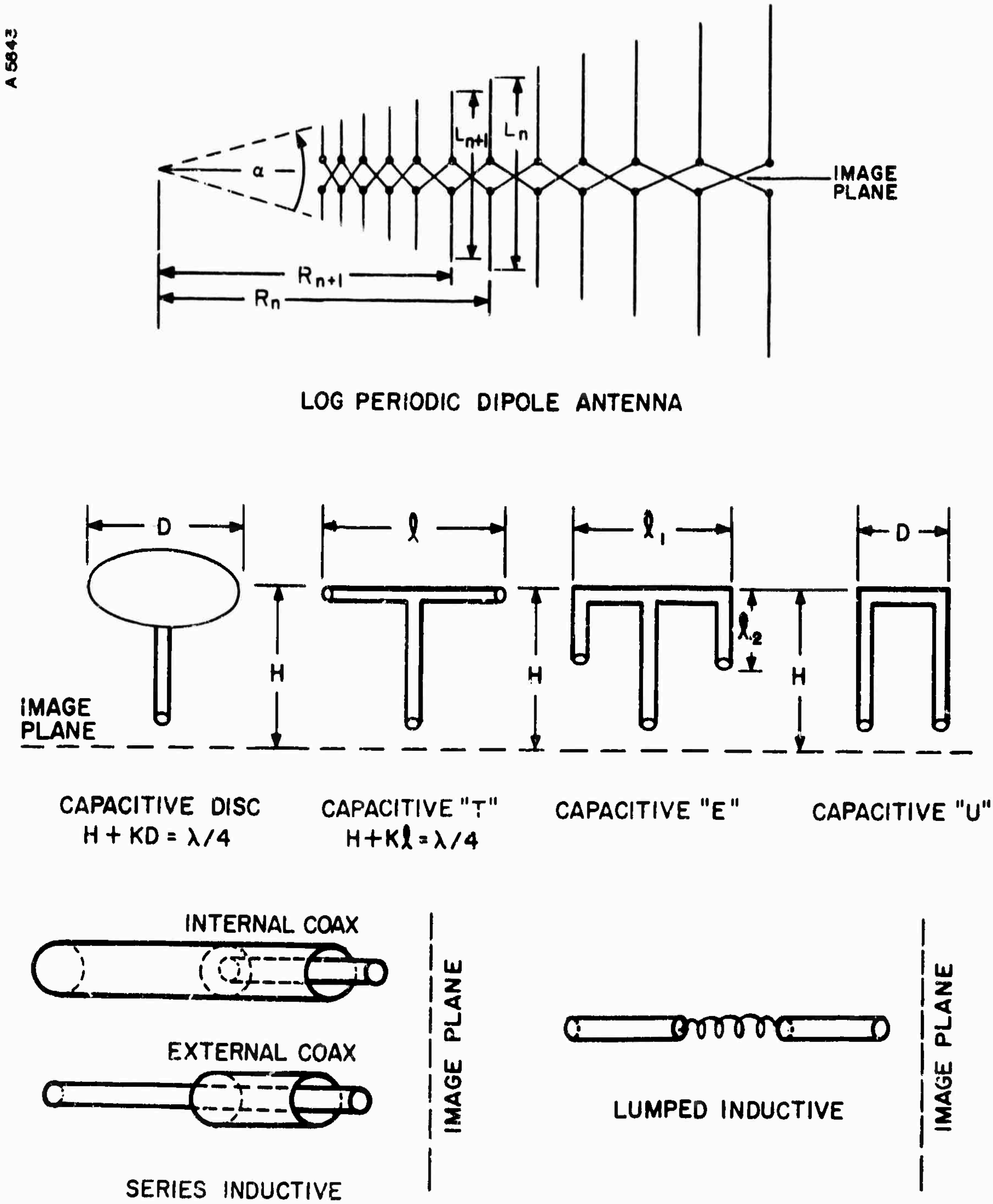

FIGURE 1. TYPES OF REACTIVE LOADING

foreshortening. In order to obtain a shortening of the elements by as much as one half, the inductive loading method described by Elfving[3] shows the most promise. Figure 2 is a sketch of a constant width, log periodic dipole array utilizing inductive coil or lumped constant loading of the individual dipoles. It was not the purpose of this study to consider the merits of loading techniques, but the effects of loading on dispersion. The effects of loading, of which Figure 2 is one example, on the parameters of a log periodic dipole antenna are of primary concern and these will be discussed.

The high frequency, or short dipole, portion of the antenna of Figure 2 is a regular log periodic dipole array, and for this region the antenna is defined by the design ratio $\tau^{\frac{1}{2}}$. Referring to the element numbers of Figure 2

$$\tau^{\frac{1}{2}} = \frac{\ell_{-1}}{\ell_0} = \frac{\ell_{-2}}{\ell_{-1}} \quad . \ . \ . \ . \ \text{etc.}$$

For frequency independent type of operation, τ and α are constants. The element spacing to length ratio, s/ℓ, is defined by

$$S/\ell = \frac{1 - \tau}{\tan \alpha/2}$$

This value should not exceed 1.3 for proper log-periodic operation. The values of τ for good design vary from 0.7 to 0.9. The larger values of τ require that more elements be used to cover a given frequency range, and that the LPD antenna be longer.

These design considerations hold for the regular portion of Figure 2, but are not sufficient for the loaded portion from element ℓ_1 through element ℓ_n. The maximum allowable length of the elment ℓ_0 determines the amount of foreshortening necessary for the low frequency element of the antenna, with the ratio defined as

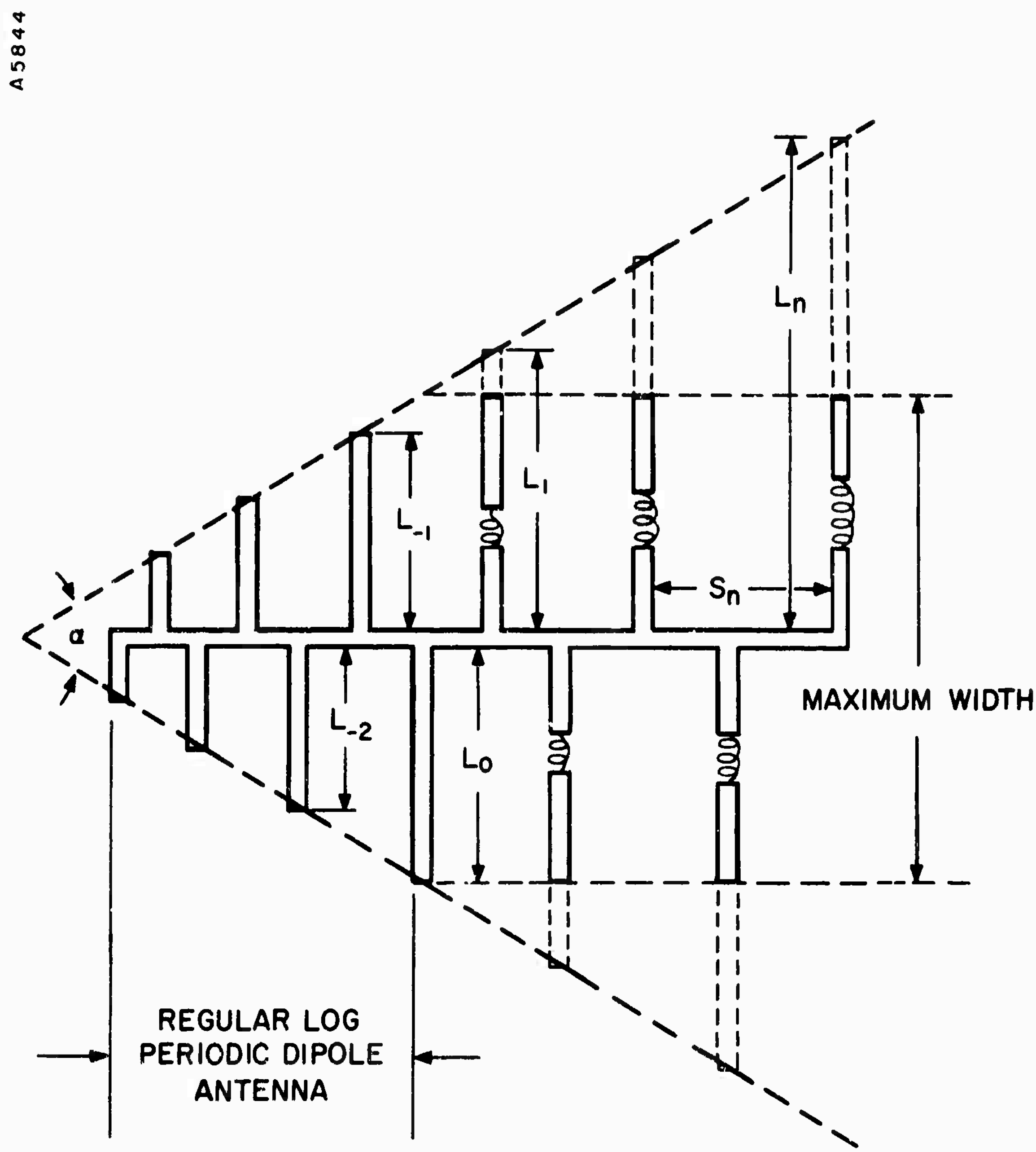

FIGURE 2. CONSTANT WIDTH LOG PERIODIC DIPOLE ANTENNA, INDUCTIVE LOADING

$$F.S. = \frac{\ell_n}{\ell_0}$$

The amount of foreshortening increases for the lower frequency dipoles, starting with dipole ℓ_0 for which little or no foreshortening is required. To maintain the same frequency independence in the loaded portion as the unloaded, the current distribution in the elements around a resonant element must be the same for the two regions. An increase in the loading of an element causes the corresponding element Q to be increased. This higher Q and the increased characteristic impedance of the elements do not allow efficient coupling between the elements in the active region and the antenna transmission line.

These problems suggest a larger value of τ in the loaded portion of the LPD antenna. The increase of τ dictates that the number of elements needed to cover a given frequency range becomes larger. The increase in the number of elements also requires an increase in the boom length, or overall antenna length.

Although the foregoing discussion was based on inductively loading the elements, the same argument holds for all the types of loading referred to in Figure 1. When the design parameters in the loaded portion of the LPD are compensated for properly, the antenna will operate with reduced efficiency but will maintain its directive properties and pseudo-frequency-independent operation.

2. DISPERSIVE PROPERTIES

A practical broadband structure, such as the LPD antenna, which can be truncated without adverse effect in a given range of operation is necessarily dispersive and not frequency independent. At best its characteristics continuously scale with frequency and its transient response is far

from ideal. Little has been published regarding the dispersive properties of an LP or in particular an LPD structure. Ordinarily, one associates the broadband nature of a device with its ability to reproduce faithfully a transient signal applied at its input. A short note published by Pulfer[8] has pointed out that the LP and CS (continuously scaled) antennas are quite dispersive and introduce distortion when used for the transmission of signals requiring a pass band which approaches that of the antenna. A typical sketch of the input and output pulses transmitted by a pair of 6 inch diameter, 16 turn spiral antennas is shown in Figure 3. The dispersive property of these antennas is evident from the diagram. The various frequency components arrive at different times, and the delay increases with a decrease in frequency.

An explanation of this phenomenon will be offered in terms of a simple model. Figure 4 is a sketch of a three-dimensional CS structure and typical current amplitude distributions for frequencies f_1 and f_2, where $f_1 > f_2$. Assume initially that there is no relative delay between the two current envelopes corresponding to f_1 and f_2 when excited by an impulse source at the input. Let P be a point in the far field. It is then clear that the lower frequency (f_2) component will experience an added delay because of the added path length $D_2 - D_1$. In a practical antenna this delay distortion is increased by the additional delay introduced by the geometry of the structure such as the transposition of LPD elements which increases the phase distortion.

It is apparent from the above discussion that increase in the length of an LPD with loaded elements at the low frequency end would tend to increase the delay distortion as well as the phase distortion. To obtain a somewhat quantitative feel for the amount of phase distortion due to increase in antenna length, it was recommended to RADC that this be calculated from the far field phase vs. frequency response for two LPDA models of different lengths but identical band widths. It was mutually decided that since RADC has a Sylvania computer program from an

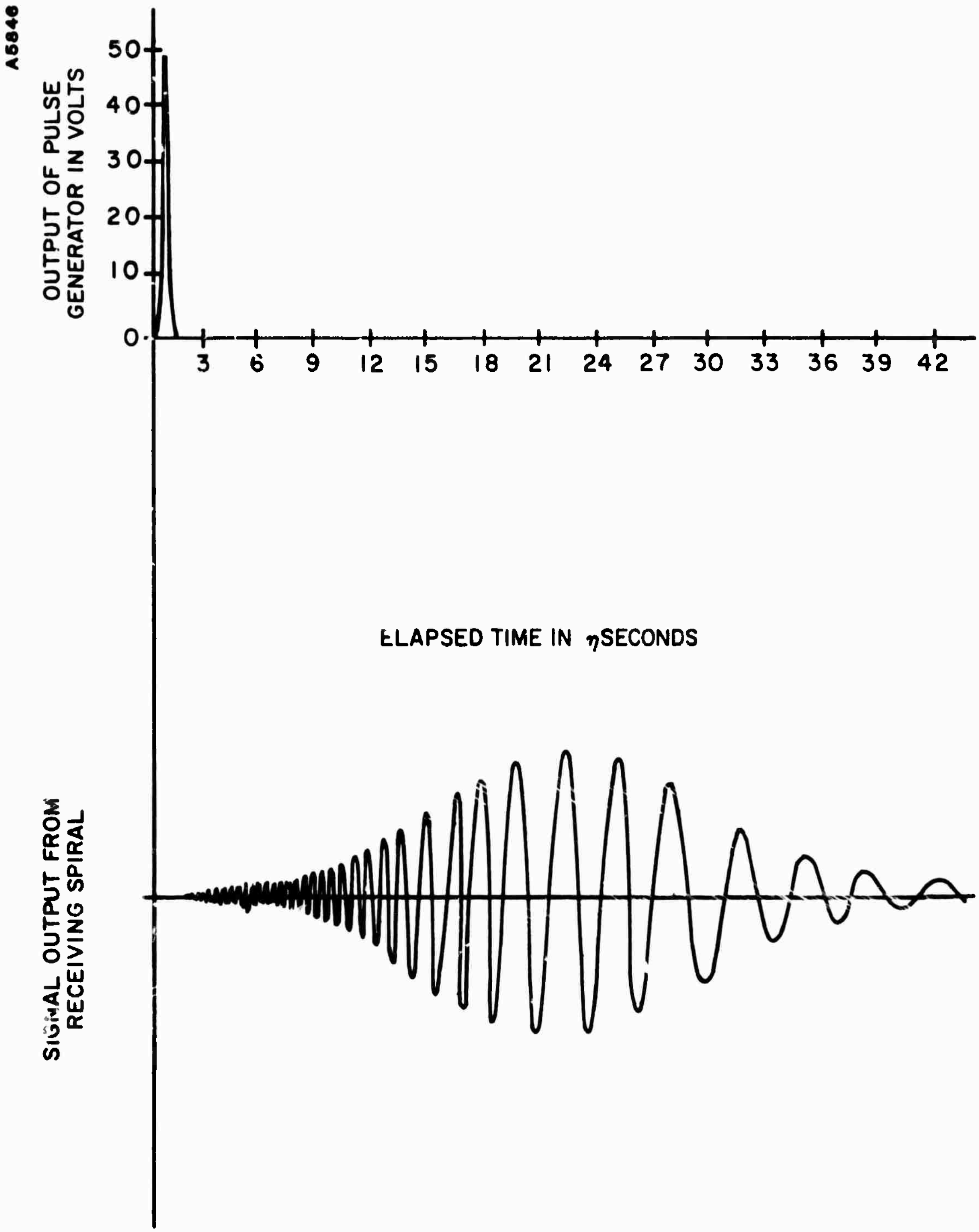

FIGURE 3. TRANSIENT RESPONSE SPIRAL ANTENNA

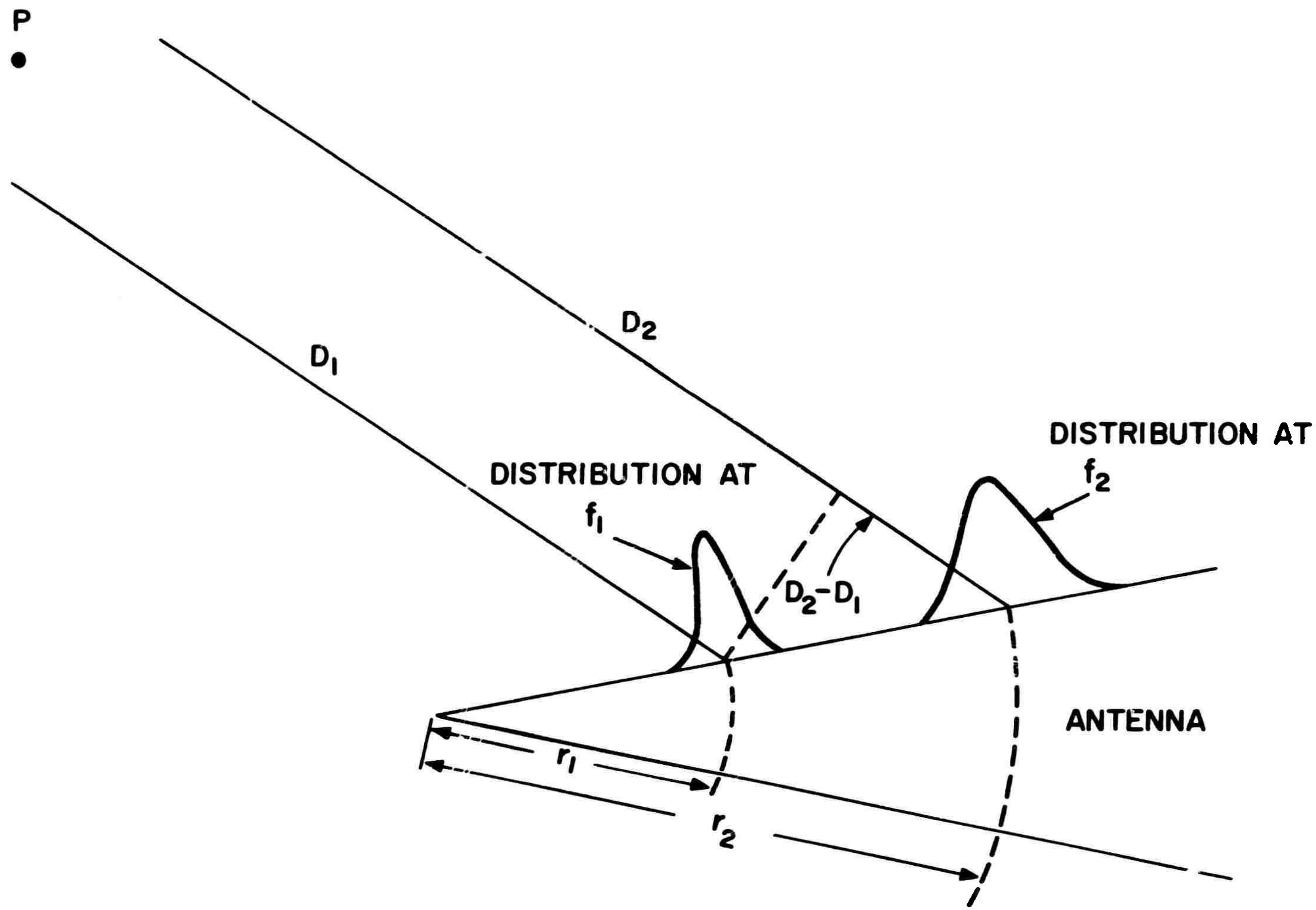

FIGURE 4. SKETCH EXPLAINING THE MECHANISM OF DELAY DISTORTION

analysis by Arens, Elfving, and Johnstone[2] et. al., that this calculation would be performed at RADC. The results of the calculation are not part of this report

3. APPLICATION OF K-β DIAGRAM TO LPD ANTENNA

The dispersion characteristics of periodic structures, of which the LPD antenna is an example, are commonly described in terms of a plot of the propagation constant β versus the wave number k. The plot is referred to as the K-β or ω-β diagram. A number of papers have been published on the application of the K-β diagram of open periodic structures to the analysis of periodic and log periodic antennas [8, 9, 10, 11, 12, 13, 14]. In particular, the Brillouin diagram of the finite uniformly periodic array has been both calculated and measured [11]. The array is the direct counterpart of the LPD array, and its behavior is typical of the expected performance of an LP structure. The prototype LP structure is generated from the uniform periodic structure by scaling the linear dimensions of each succeeding cell by the scaling factor τ.

The Brillouin diagram in its various forms offered a convenient way of summarizing phase and amplitude performance along a periodic structure. Considerable work has been carried on in the extension of this theory of uniform structures to apply to LP structures, and hence to further the understanding of the principles of operation of the LP antennas. It was decided, in view of the amount of work underway that this portion of the study be limited to a literature search to avoid duplication and conserve resources of this contract.

Specifically, work was performed in this area at the antenna laboratory of the University of Illinois. Reports by Mittra and Jones [7, 9, 11], Ingerson and Mayes[10], and Stephenson and Mayes[6] are listed in the bibliography.

The work consisted of theoretical and experimental study of periodic

structures, both continuously scaled and log periodic. The use of K-β diagrams and their significance in analyzing the structures was emphasized. The multimode characteristics of the array structures was observed, and the limitations this phenomenon places on the means of analyzing the structures noted. Good agreement between theoretical and experimental results was indicated.

The use of the K-β diagram and a generalization of Floquet's Theorem for periodic structures to successfully predict the type of structures which would exhibit the required broadband characteristics was discussed. In particular the LPDA and conical spiral were analyzed, and showed good agreement with the experimentally observed characteristics.

These papers indicated that the problem of designing a frequency independent antenna with ideal transient response has not been solved. It is this author's opinion that the Multifilar Helix Antenna, reported on in Part II of this report, is a step closer to this goal.

4. CONCLUSION

The Log Periodic Dipole Antenna along with other Log Periodic and continuously Scaled Antennas, is a highly dispersive structure. The dispersive properties of the LPD are increased when the low frequency dipoles are foreshortened by means of reactive loading, due mainly to the resulting increase in antenna length and number of elements.

The effects of the loading on the frequency response of the log periodic dipole antenna considered for an instantaneous bandwidth of 10% or 1 MHz, whichever is greater, is relatively small. Since the phase is proportional to the log of frequency, a 10% change in the frequency causes less than a 6% deviation from phase linearity for the normal L. P. This deviation is for phase corrected for front truncation of the L. P. (Ref. 1, Sect. 3.5.2).

When the antenna elements are foreshortened, causing an increase in τ, and corresponding increase in antenna scaling factor τ^2, the 10% signal bandwidth results in further deviation from linearity proportional to the increase in τ. A 10% increase in τ would result in an additional 2-3% increase in the deviation from linear phase. This figure is again exclusive of truncation effects and change in phase center of the antenna due to frequency change.

5. RECOMMENDATIONS

a. The program to calculate the change in phase response due to increased length of an LPD antenna should be run on the computer and results analyzed for effects on the overall array.

b. The transient response of the LPD element and of the array should be investigated. Little has been published regarding the general analysis of the transient response of wide-band antennas, and for the OHR application it would seem to be an important factor in the system operation. Laboratory measurements similar to those mentioned in this report could be made on individual LPD models using various pulse shapes and pulse lengths. In addition, an analysis program to relate the LPD response to the array operation would be in order.

REFERENCES

1. Carrel, R. L., "Analysis and Design of the Log-Periodic Dipole Antenna", Technical Report No. 52, Antenna Laboratory University of Illinois, Urbana, Illinois.

2. Arens, V. R., Elfving, C. T., and Johnstone, D. L. et. al., "H. F. Antenna Optimization Study", Technical Report No. RADC-TR-67-161, August 1967.

3. Elfving, Claes T., "Foreshortened Log Periodic Dipole Array", Wescon 1963, Part I.

4. Bullock, Elfving, and Miller, "Log Periodic Antenna Techniques", A.D. 649838.

5. Di Fonzo, D T., "Reduced Size Log Periodic Antennas", Microwave Journal, Dec. 1964.

6. Stephenson, D. T. and Mayes, P. E., "Log Periodic Helical Dipole Antennas", Wescon 1963.

7. Mittra, R. and Jones, K. E., "Theoretical Brillouin (K-β) Diagram for Monopole and Dipole Arrays and Their Application to Log Periodic Antennas", Technical Report No. 70, Antenna Laboratory, University of Illinois.

8. Pulfer, J. K., "Dispersive Properties of Broadband Antennas", Correspondence Proc. I. R. E., Vol. 47, pp. 644, March 1961.

9. Mittra, R. and Jones, K. E., "Some Theoretical Aspects of Log Periodic and Continuously Scaled Antenna Designs", Technical Report No. 76, Antenna Laboratory, University of Illinois.

10. Ingerson, P. G. and Mayes, P. E., "Dispersion Properties of Linear Dipole Arrays", Antenna Laboratory Report No. 66-2, University of Illinois.

11. Mittra, R. and Jones, K. E., "Some Interpretations and Applications of the K-β Diagram", Technical Report No. 84, Antenna Laboratory, University of Illinois.

12. Kieburtz, Richard B., "Analysis and Synthesis of Aperture Fields of Log Periodic Antennas", Scientific Report No. 2, State University of New York at Stony Brook.

13. Sun, David F-D and Kieburtz, R. B., "Dispersion Relations of Periodic and Log Periodic Dipole Arrays with Parasitic Elements", Technical Report No. 92, College of Engineering, State University of New York at Stony Brook.

14. Du Hamel, R. H. and Barry, D. G., "Logarithmically Periodic Antenna Array", I. R. E. Wescor Convention Record, Part I, 1958.

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13. ABSTRACT

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The task covered in Part II of this report was to investigate the feasibility of the Multifilar Counterwound Helix as an element of a wideband array. This included design of an element and measurement of its parameters over a four to one frequency band. The result of this study was to be a model of the antenna with measured data characterizing its performance.

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